Reconstructed jet probes of small and large systems with the PHENIX detector

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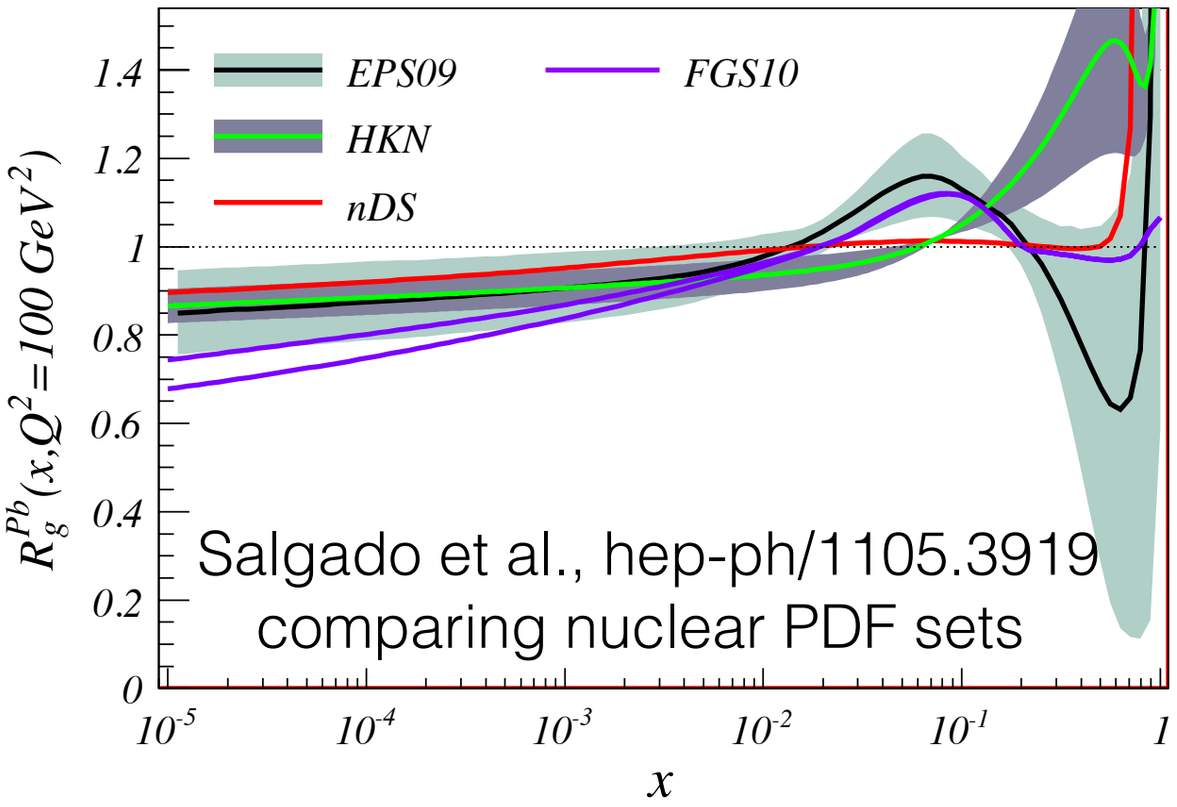
Jets in **small** and **large** systems



- Benchmark of jet production in nuclear environment
- Given collective signatures, search for "QGP"-like energy loss?

  ➡ *see talk by J. Orjuela-Koop*

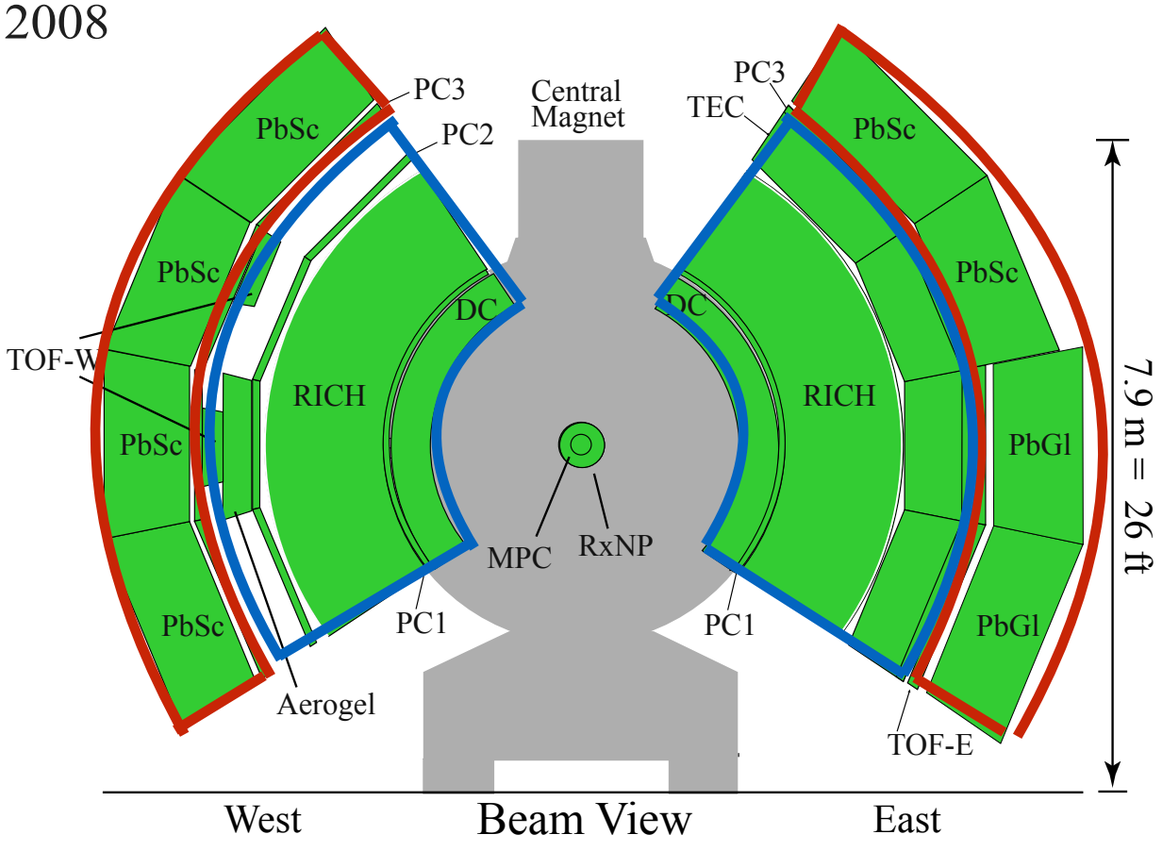
in quark-gluon plasma

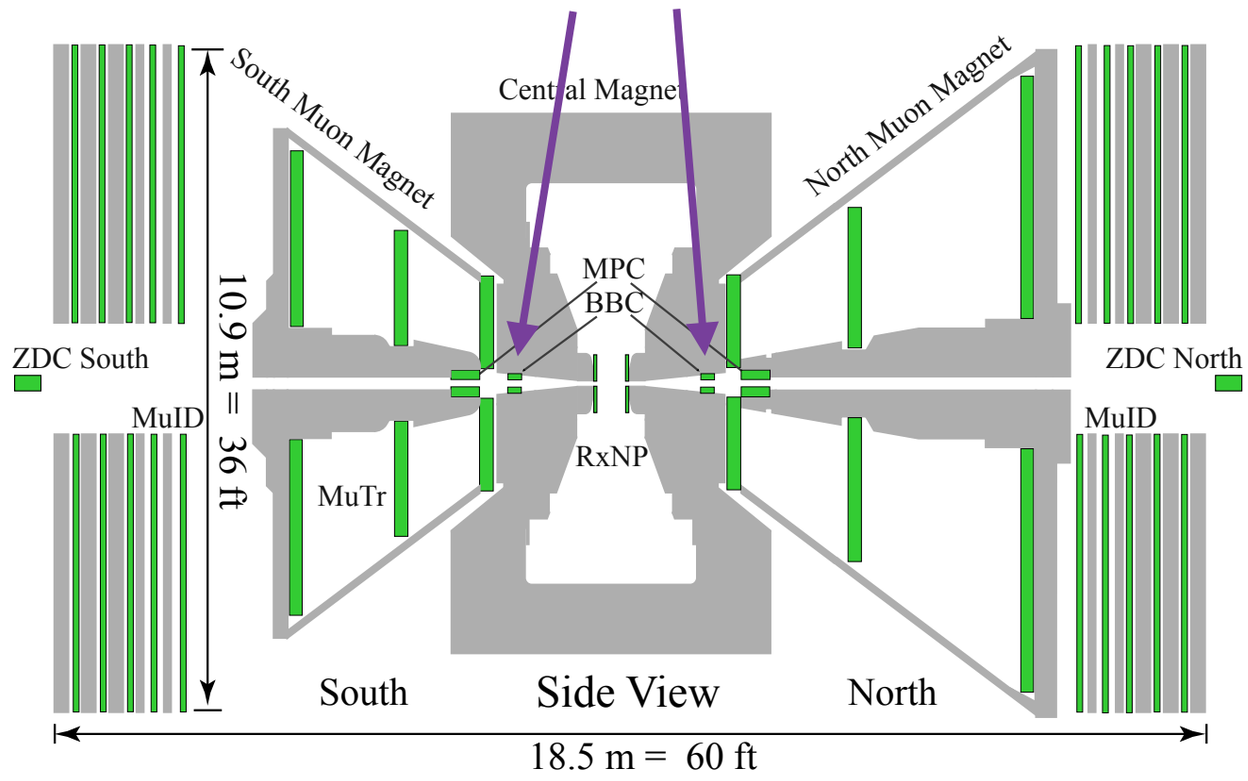
- Parton shower develops *<u>in evolving QGP medium</u>*

  ➡ *internally-generated, multi-scale probe* of QGP properties

PHENIX detector

2008





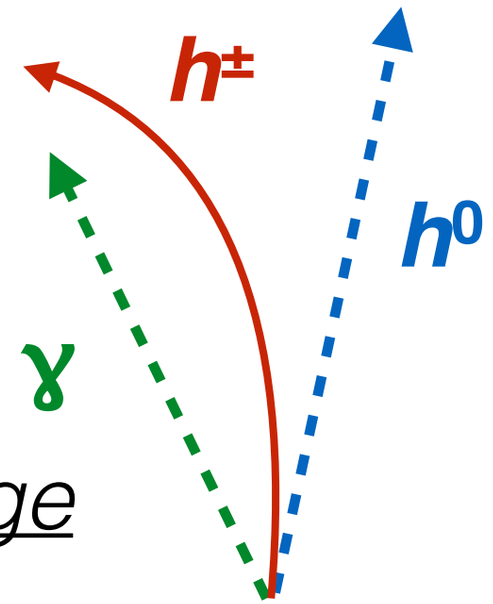
- **Drift & pad chambers** for measuring charged-particle tracks

  ➡ both subsystems cover $|\eta| < 0.35$, with two $\Delta\phi = \pi/2$ Arms

- **Electromagnetic calorimeters** with ≈18λ (PbSc) or ≈14λ (PbGl)
- **Beam-beam counters** ($2.1 < |\eta| < 3.8$) provide MB event definition and centrality classification
- Online hardware-based trigger on energy deposit in EMCal

Analysis overview

- Cluster EMCal **energy deposits** + charged-particle **tracks**
  - ➡ jet core required to be away from detector edge
  - ➡ strict run-level, particle-level, jet-level QA to ensure *good measurement of jet energy*
- GEANT simulation of detector response & embedding into minimum-bias HI data events
- Capture *≈0.65-0.70 of jet momentum on average*
  - ➡ 25%“resolution” from fluctuations in (mostly unmeasured) **neutral hadronic** component
  - ➡ correct spectra *for detector effects* with unfolding



Jet results from PHENIX

- ***d*+Au** and ***p*+*p*** jet spectra (2008 data)

  ➡ Phys. Rev. Lett. 116 (2016) 122301

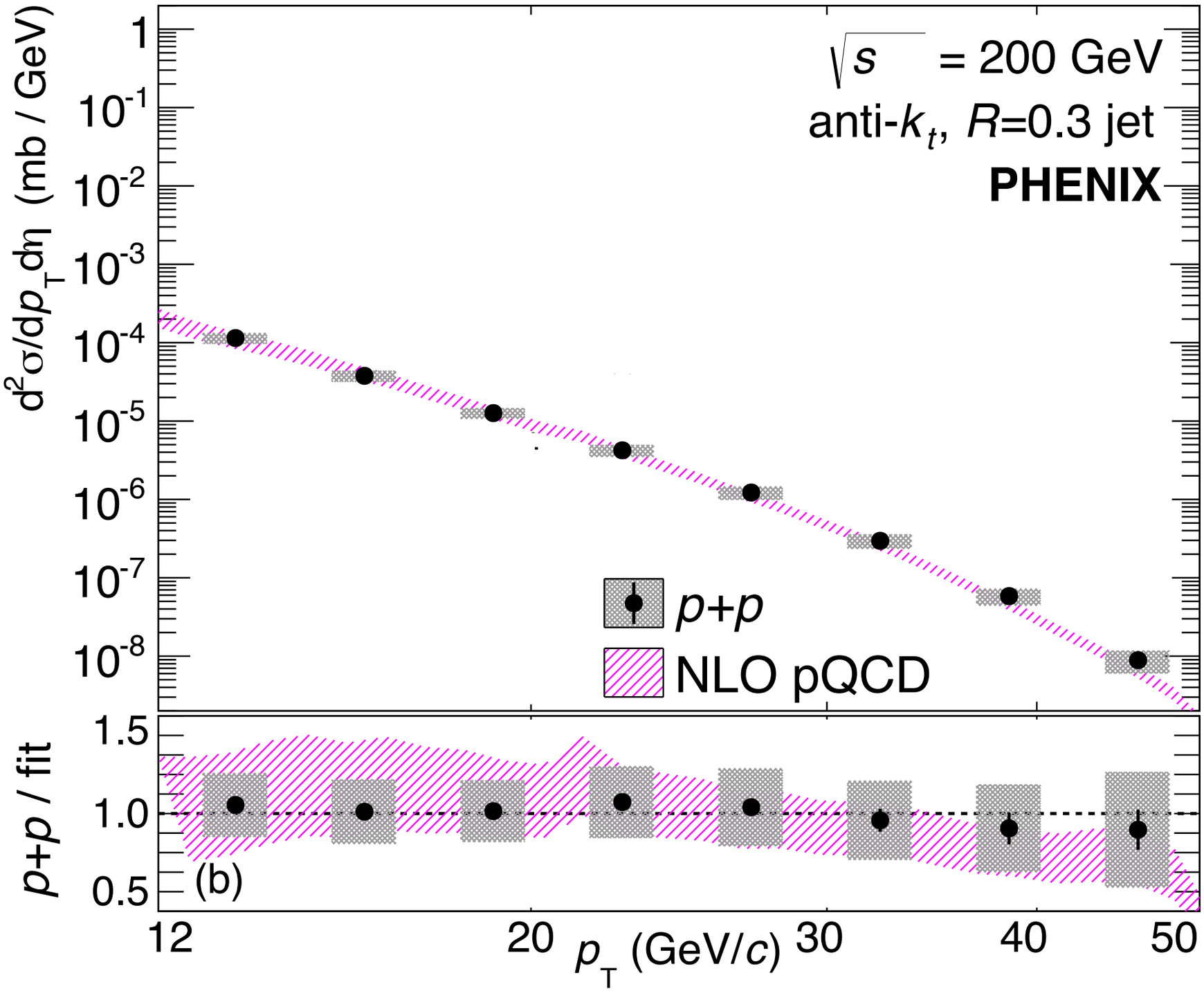
  ➡ R=0.3 anti-k_t algorithm, *<u>establish pQCD and cold nuclear matter baseline</u>*

- **Cu+Au** and ***p*+*p*** jet spectra (2012 data)

  ➡ Preliminary measurement, R=0.2 anti-k_t algorithm due to demands of HI environment

  ➡ *<u>first look at inclusive suppression of full jets</u>*

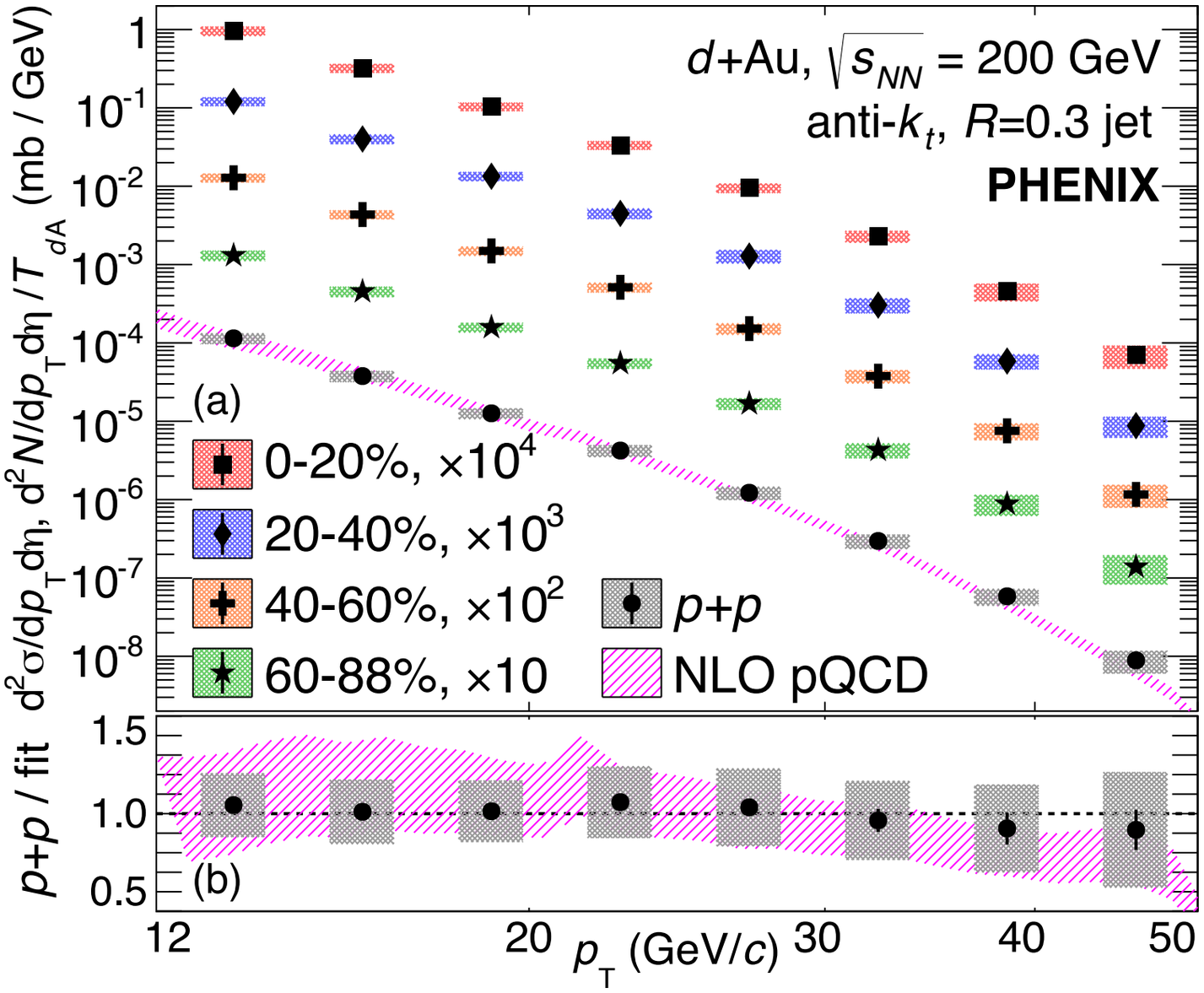
Jet spectra in *p*+*p* collisions



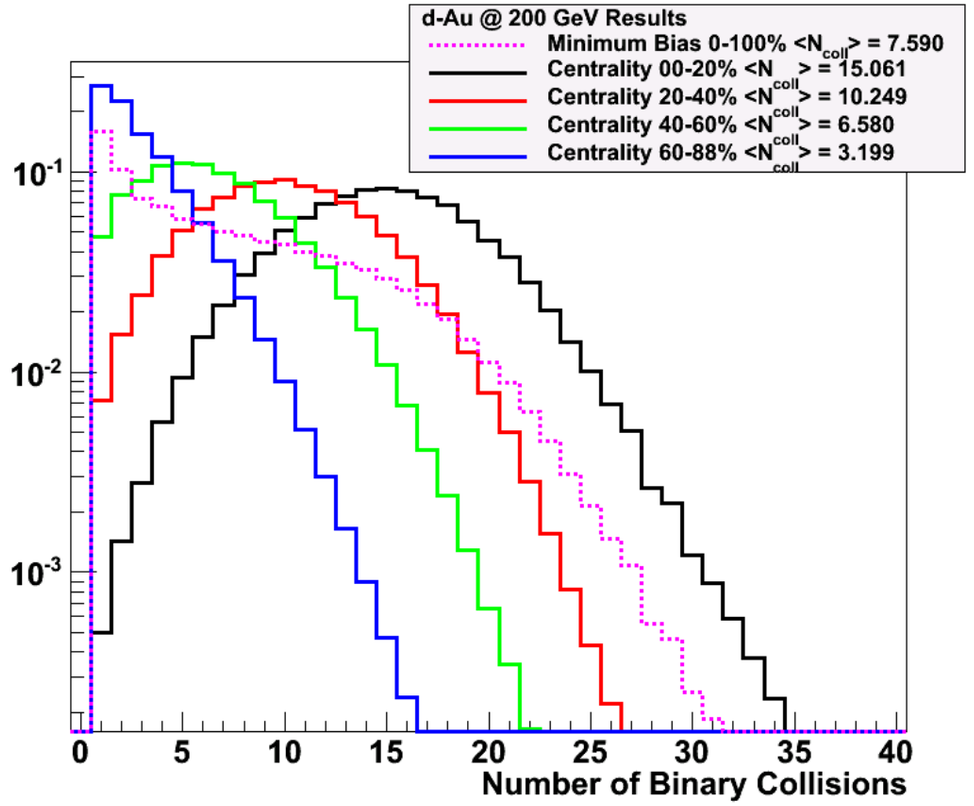
NLOJET++ w/ NNPDF2.3 and hadronization corrections from Pythia

- ***p+p* spectra**: compare favorably with **NLO *p*QCD** calculation
  - ➡ validates jet reconstruction & correction procedure

Jet yields in *d*+Au



- First measurement of jet production in asymmetric systems at RHIC

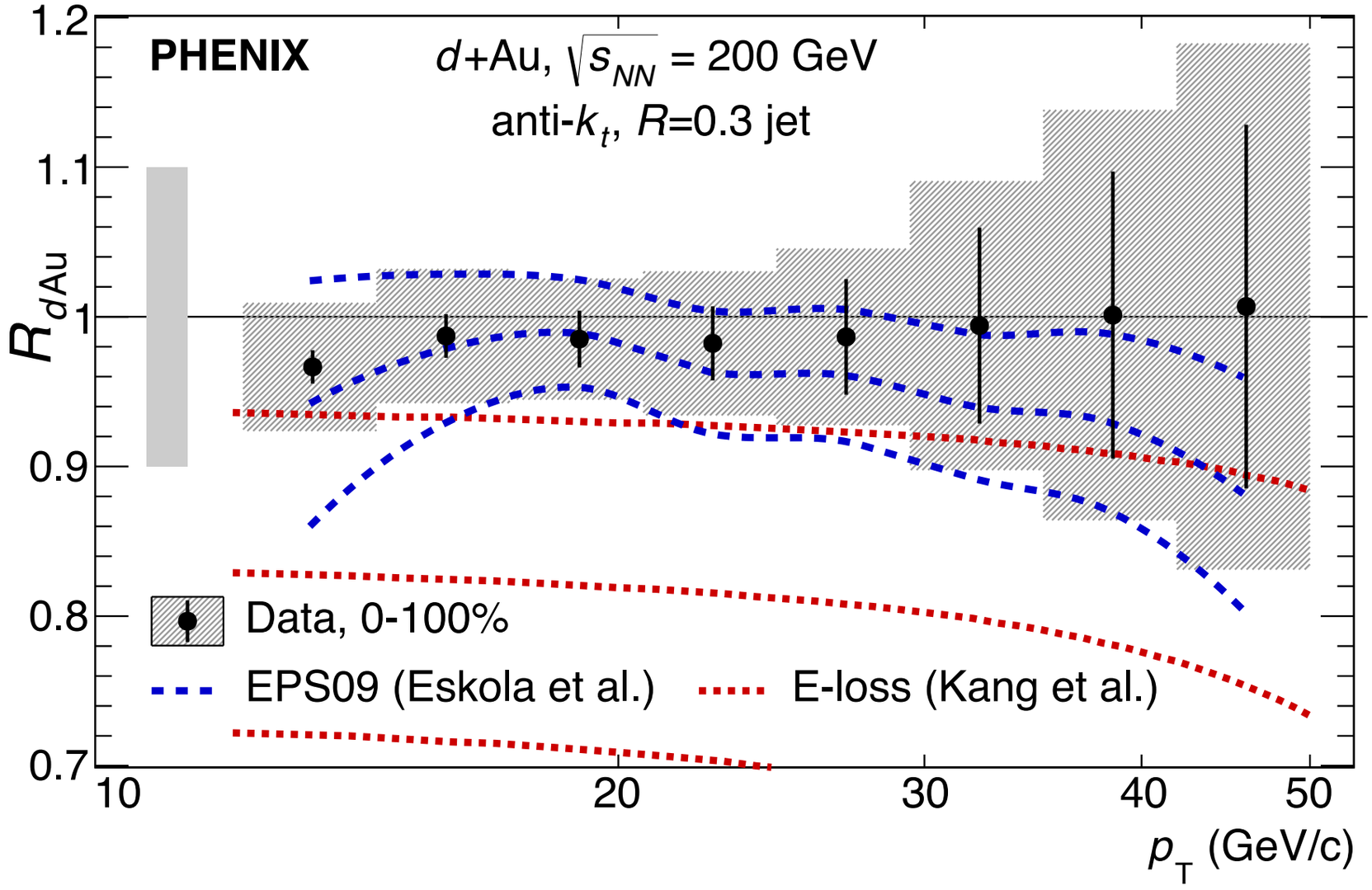


- Centrality from with Au-going beam-beam counter ($-3.8 < \eta < -2.1$) signal

➡ successful with previous hard and soft observables

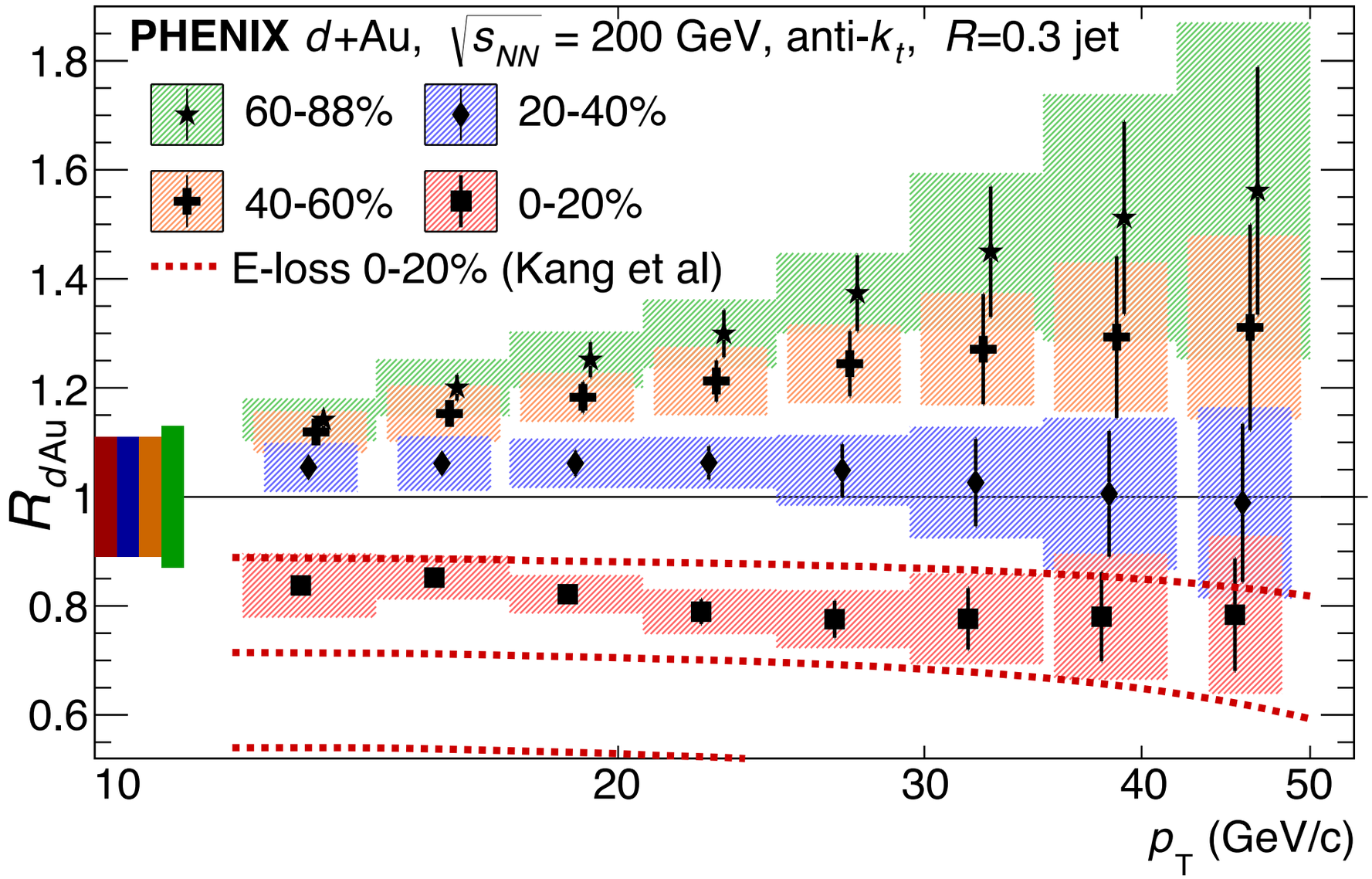
Minimum bias jet rate

$$R_{\mathrm{dAu}} = \mathrm{d}N^{d+\mathrm{Au}}/\mathrm{d}p_{\mathrm{T}} \;/\; T_{\mathrm{dA}} \times \mathrm{d}\sigma^{\mathrm{p+p}}/\mathrm{d}p_{\mathrm{T}}$$

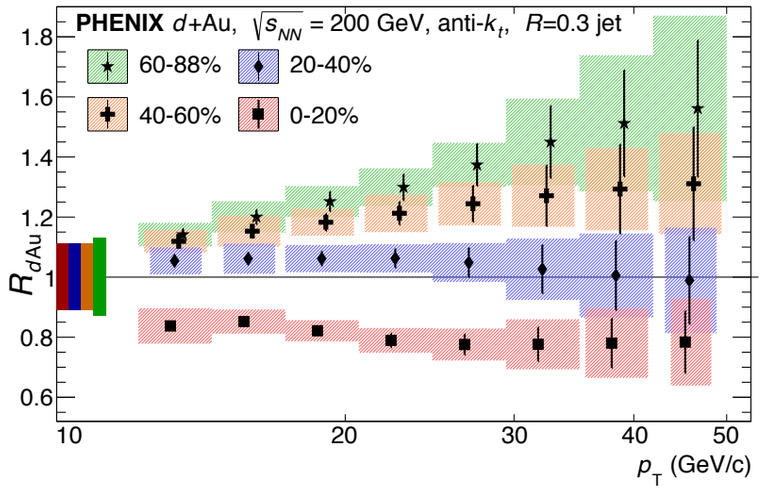


- In centrality-integrated collisions, $R_{d\mathrm{Au}} = 1$
  - ➡ consistent with global nuclear PDF analyses (**EPS09**)
  - ➡ within an **initial state E-loss calculation**, favors only small *parton* ↔ *nuclear material* momentum transfer

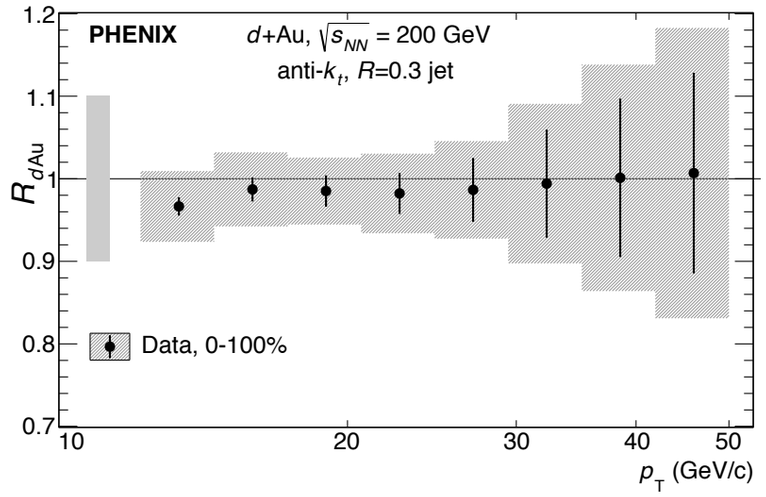
Centrality-selected jet rate



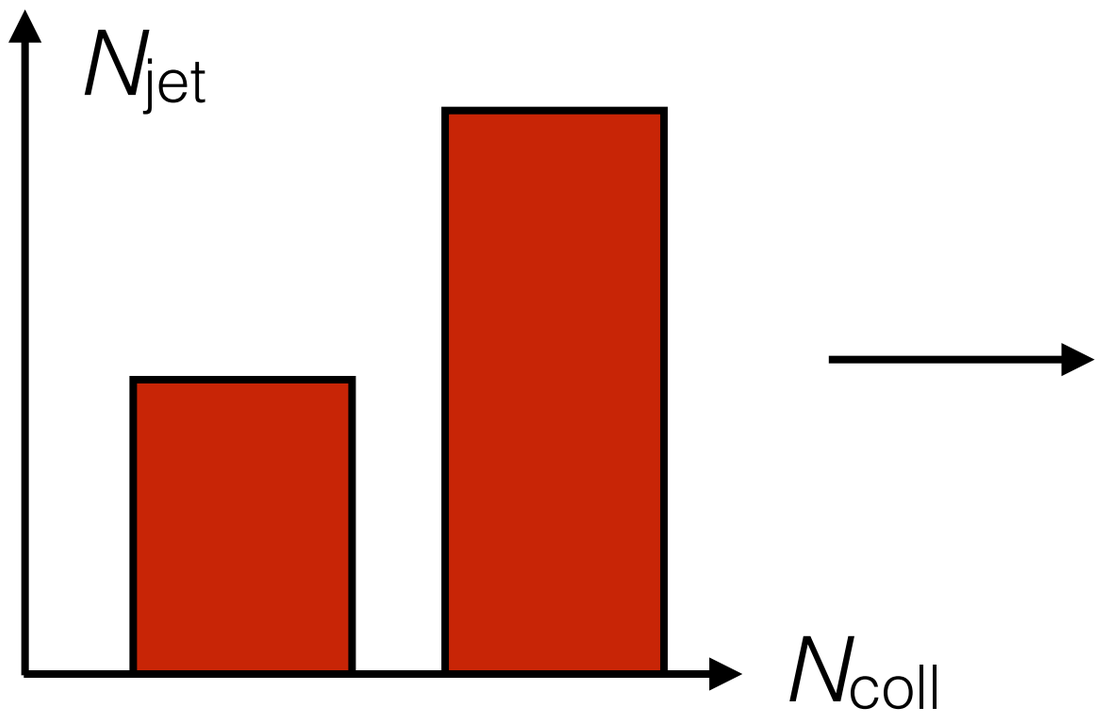
- Suppression of jet rate in **central 0-20%** (large N_{coll}) events
  - ➡ comparable with initial state E-loss calculation?
- Enhancement in **40-60%** and **60-88%** (small N_{coll}) events
  - ➡ very challenging to explain within existing frameworks…

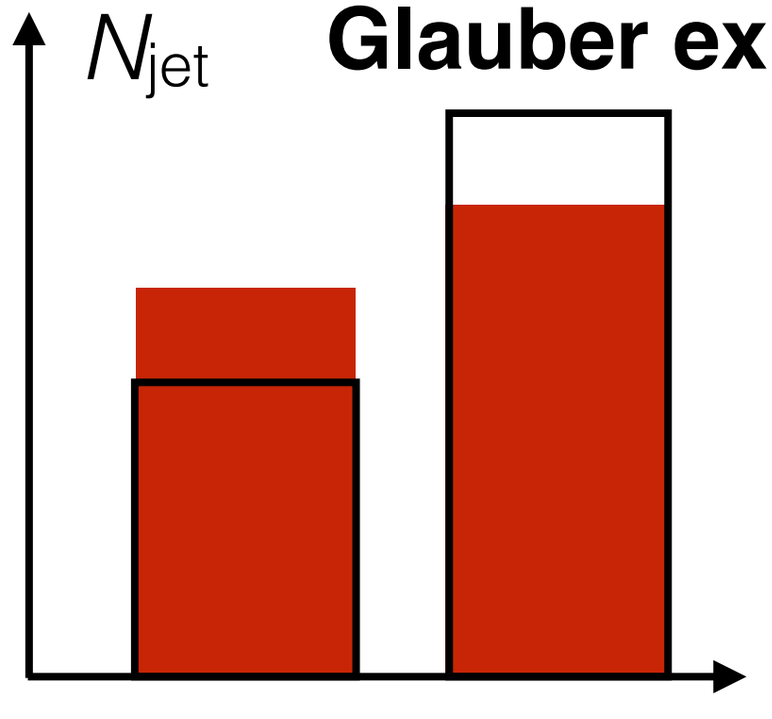


vs.



?





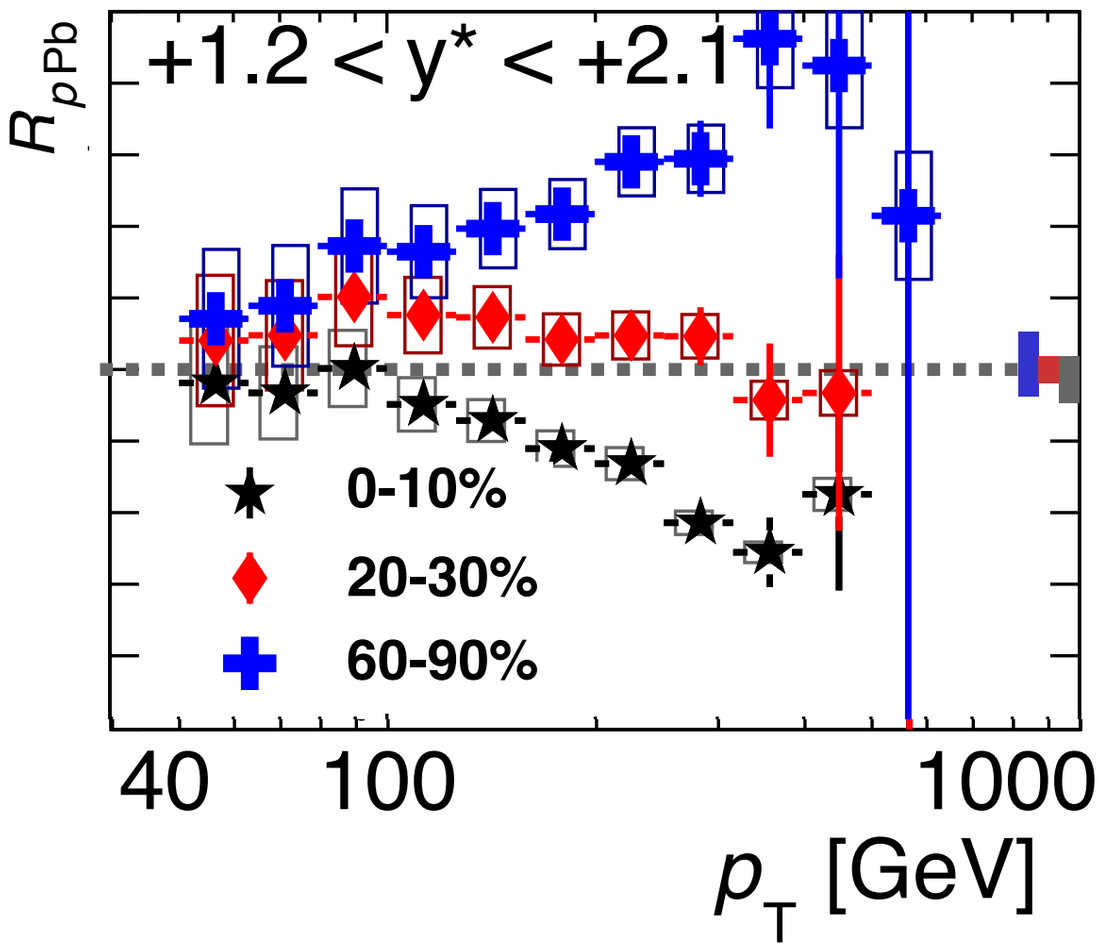
Glauber expectation

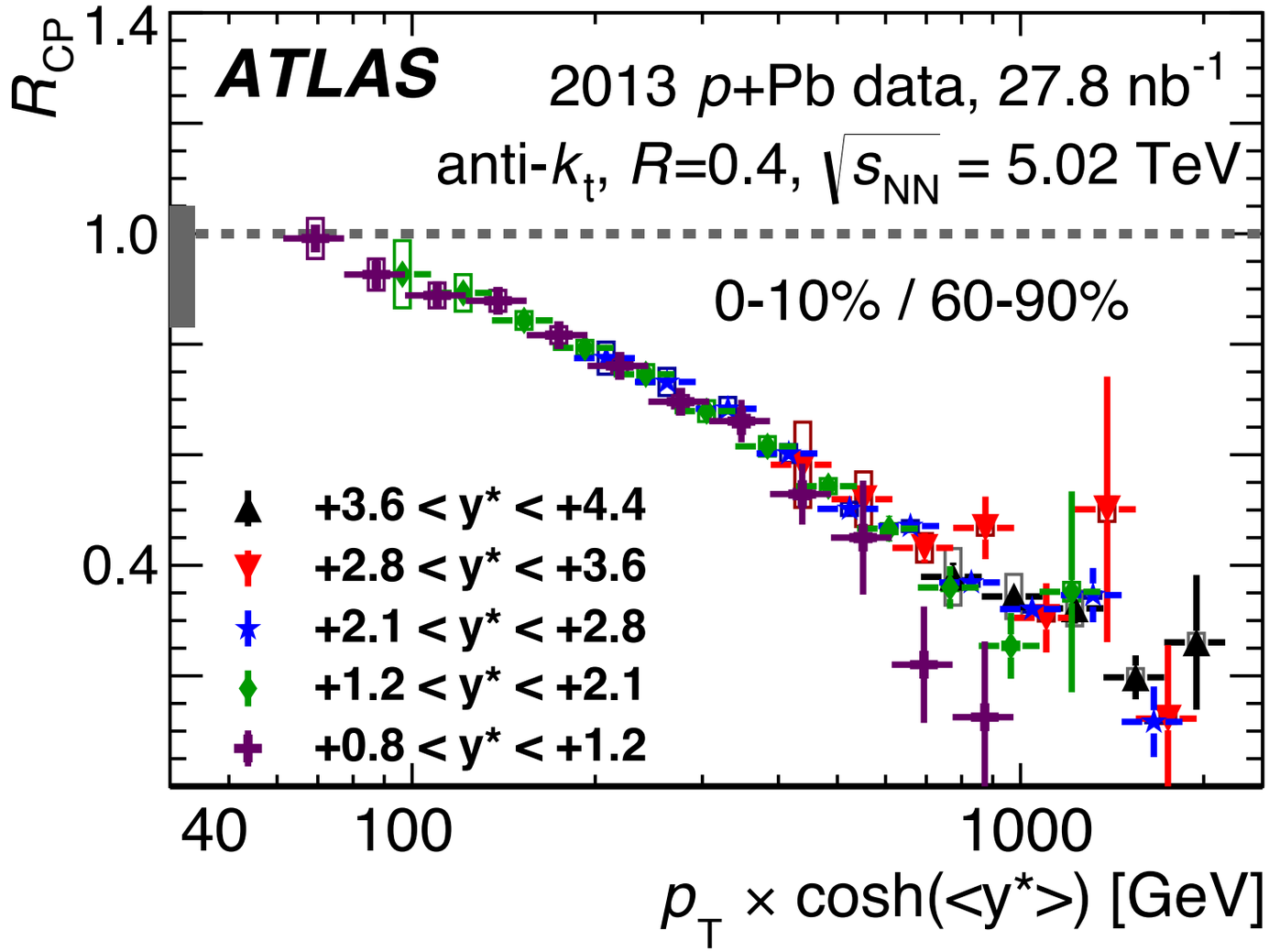
data

- Occam's razor: *<u>jet production unmodified</u>*, but *<u>multiplicity in Au-going direction is modified in jet events</u>*
  - ➡ e.g. jet events merely re-rearranged in centrality, so minimum-bias R_{dAu} = 1 by construction

Analogous LHC results

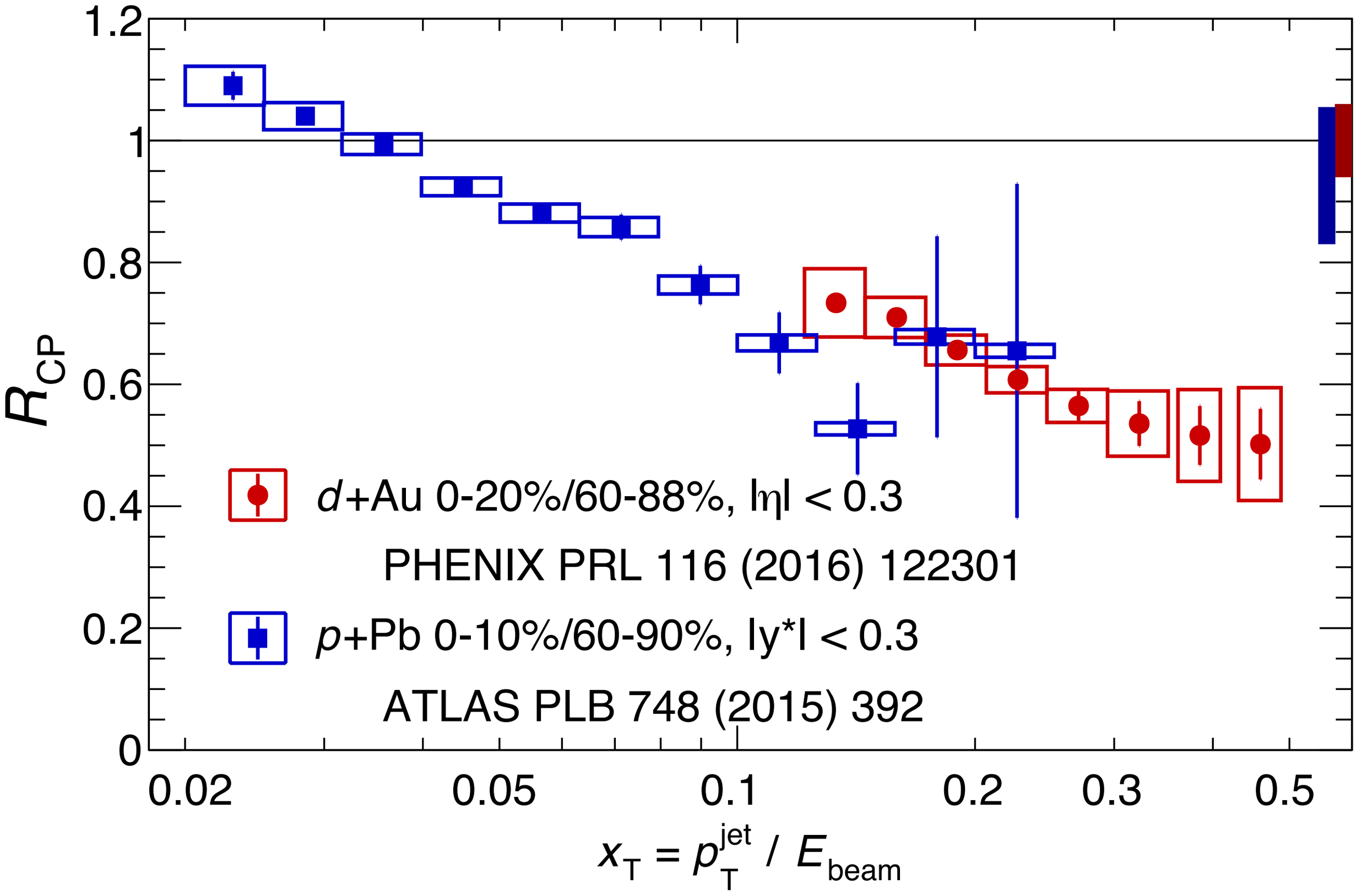
PLB 748 (2015) 392





Same modification pattern, in the same Bjorken-*x* range

Modifications scale with *proton-x* and do not depend on nuclear-*x*…



Common "initial state" proton-x effect at RHIC and the LHC?

Proton spatial configurations

$|\Psi_{proton}\rangle$ = (3q) + (3q+g) + (3q+π) + …

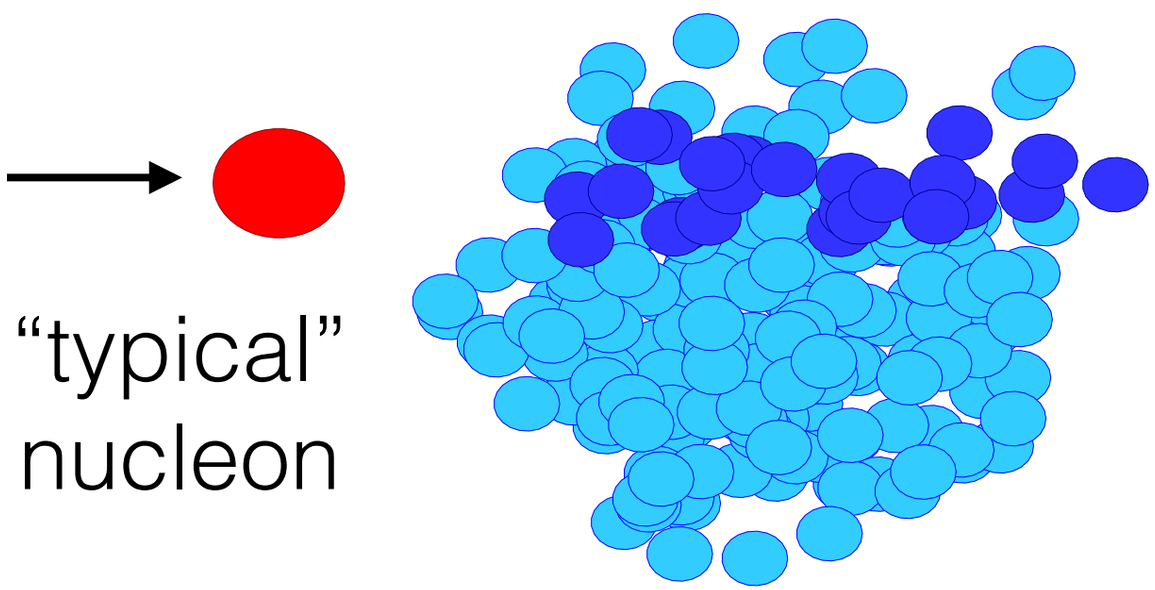
$|\Psi_{proton}$; *large x*$\rangle \approx$ (3q)

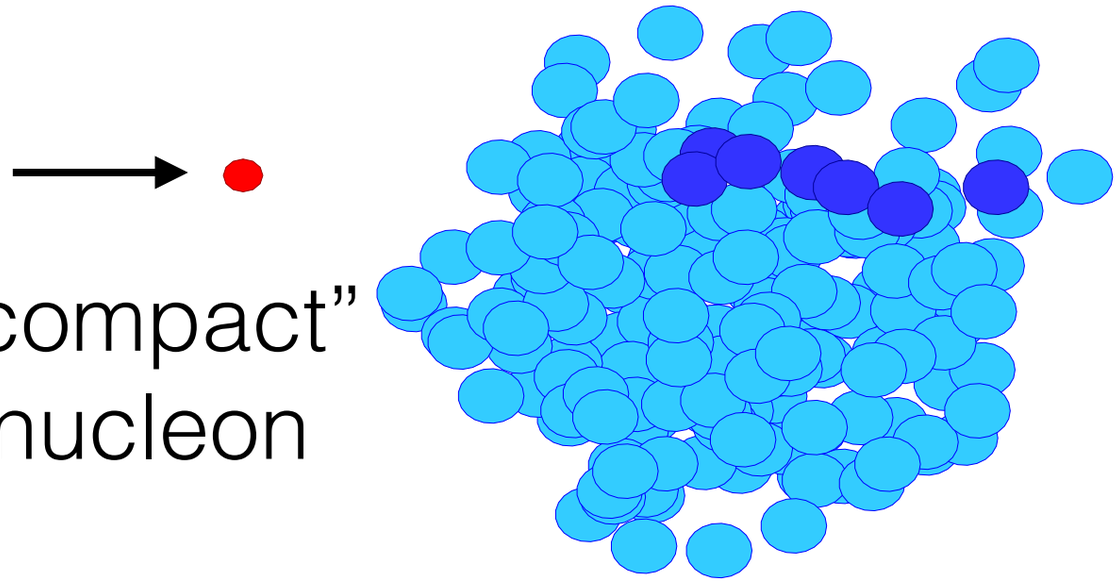
DVP, B. Cole, M. Strikman, PRC 93 (2016) 011902

- *One idea:* this is a consequence of proton color fluctuations at collider energies
  - ➡ correlation between *spatial* and *momentum* structure
  - ➡ configurations with a high-*x* parton (≳0.1) are "small": fewer other partons, smaller transverse size, etc.

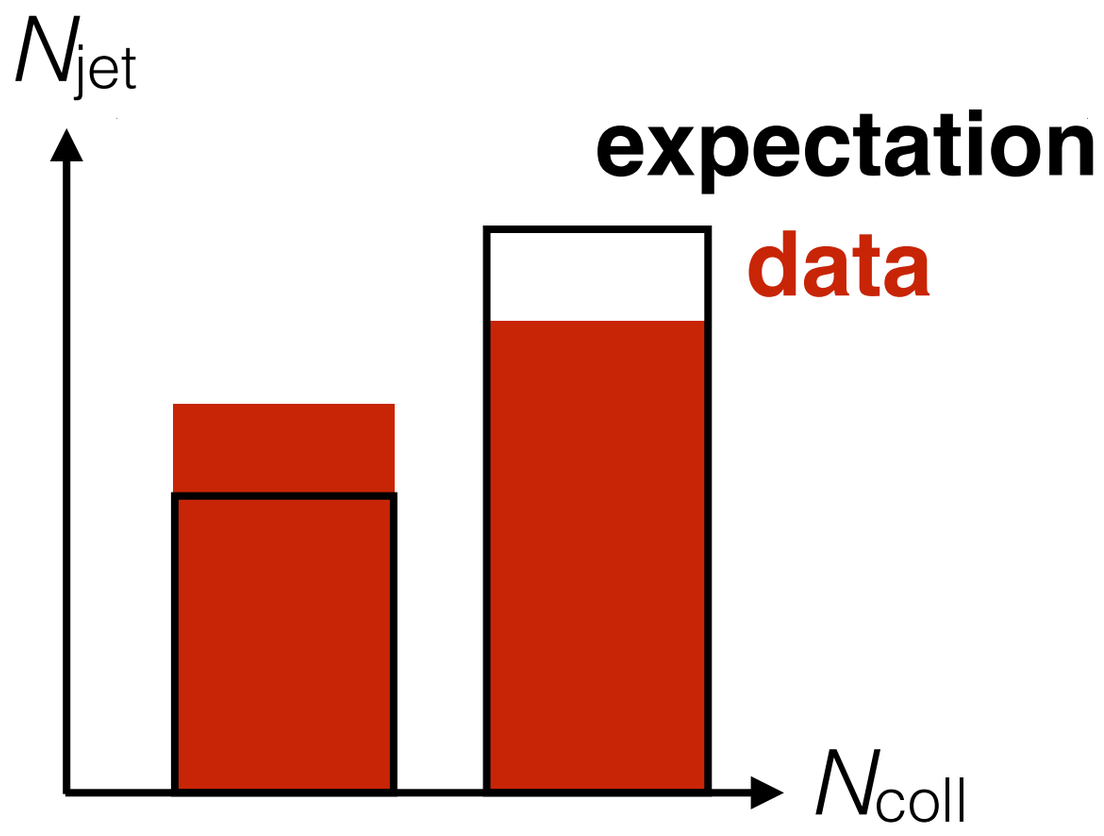
See also Bzdak et al. hep-ph/1408.3156, Armesto et al. PLB 747 (2015) 441

Geometric interpretation





compact, large-x
proton configurations
strike fewer nucleons



Projectile-species dependence

- Explore these effects further this with a "projectile-species" scan at RHIC
- For QGP-induced E-loss:

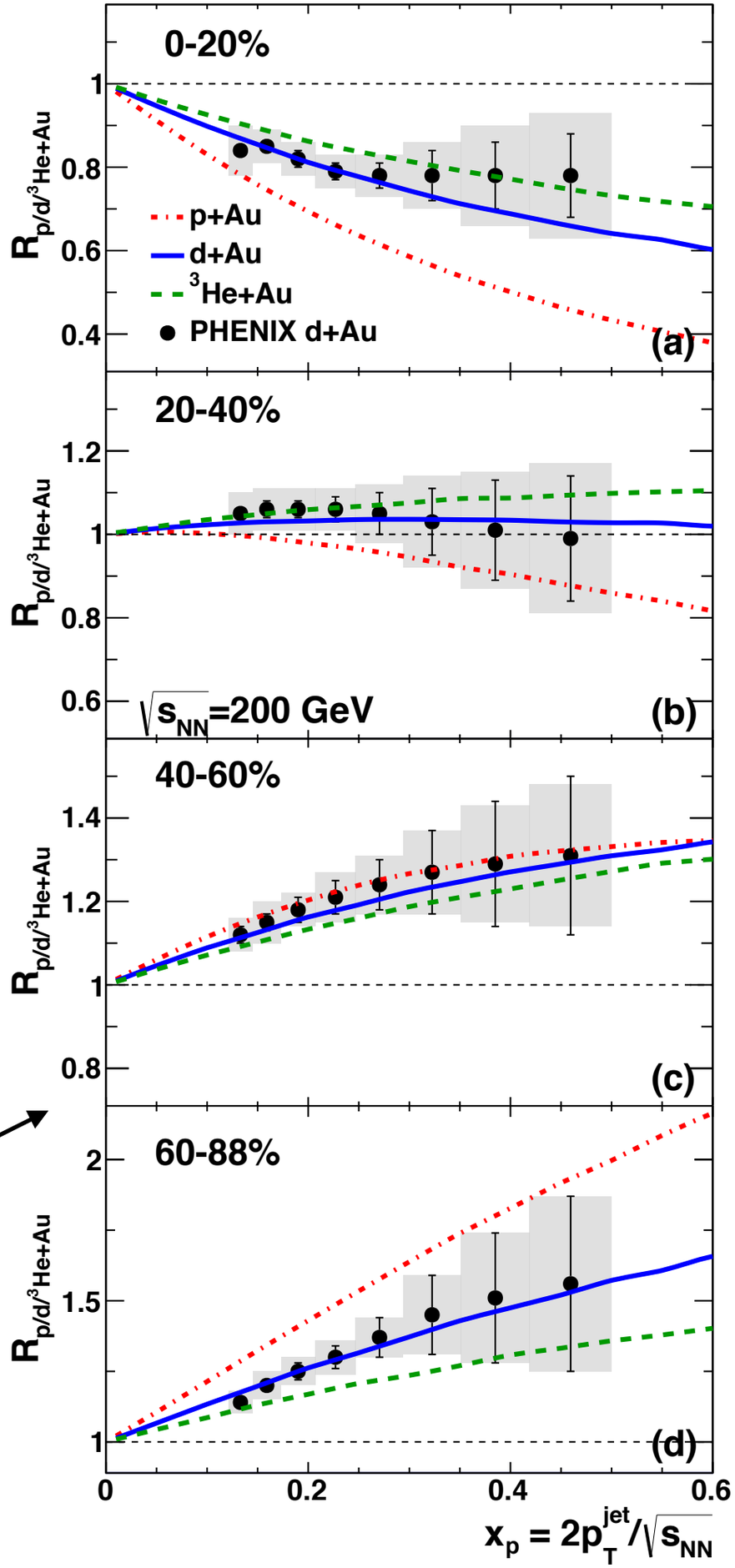
  ➡ $R_{\mathrm{pAu}} > R_{\mathrm{dAu}} > R_{\mathrm{3He+Au}}$ (central events)

- For a shrinking proton size, effect washed out by $1/A_{\mathrm{projectile}}$:

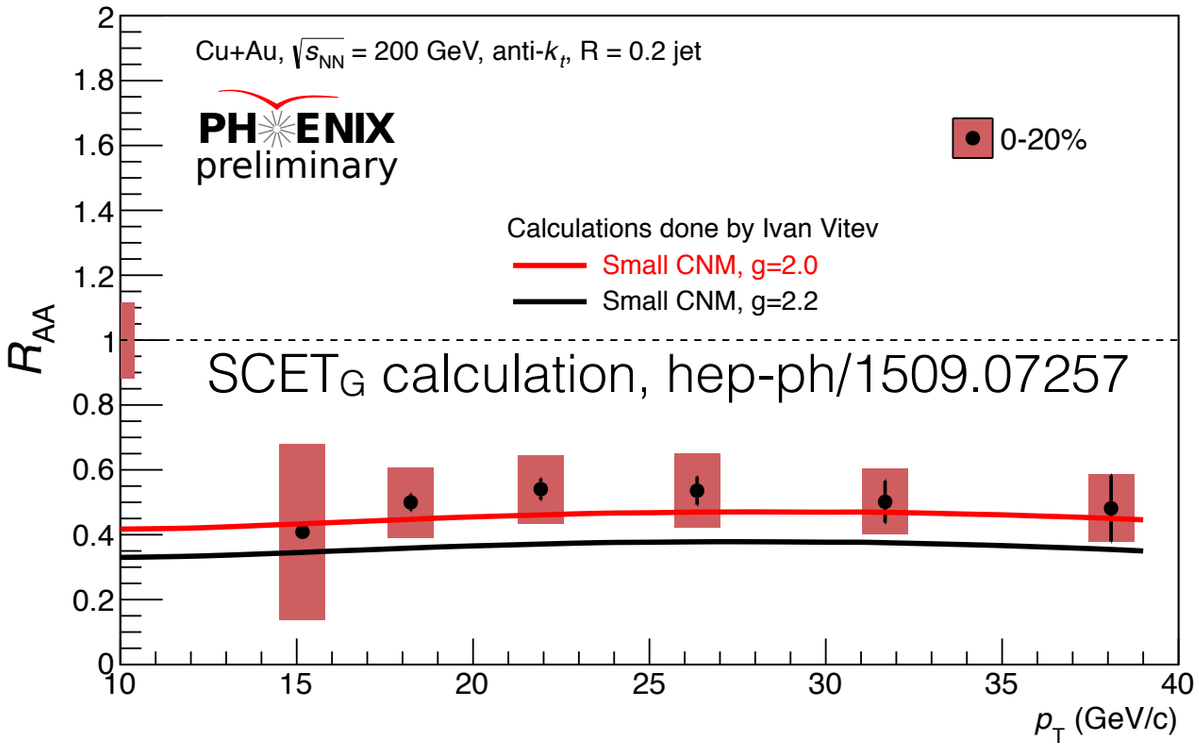
  ➡ $R_{\mathrm{pAu}} < R_{\mathrm{dAu}} < R_{\mathrm{3He+Au}}$ (central events)

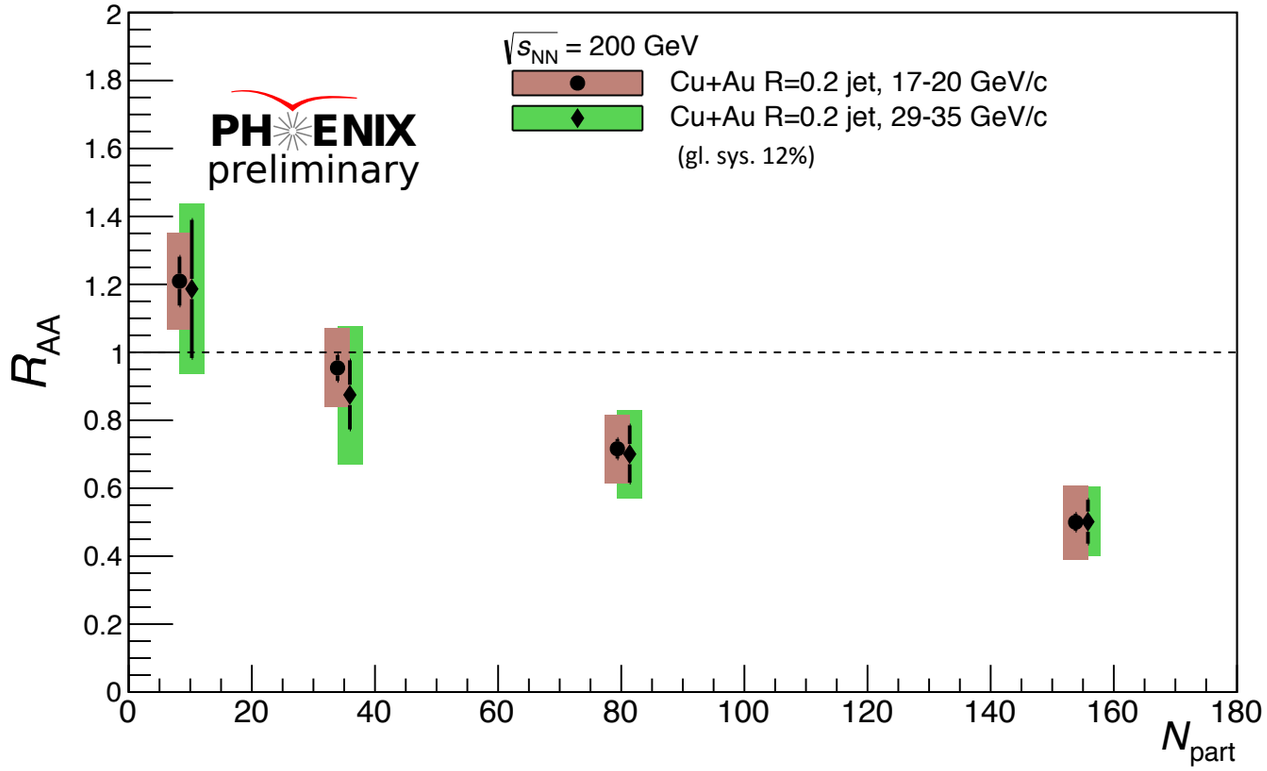
- After tuning a simple model to ***d*+Au**, predict ***p*+Au** and **^{3}He+Au**

  ➡ DVP, J. Nagle, D. McGlinchey, nucl-th/1603.06607



Jet suppression in Cu+Au



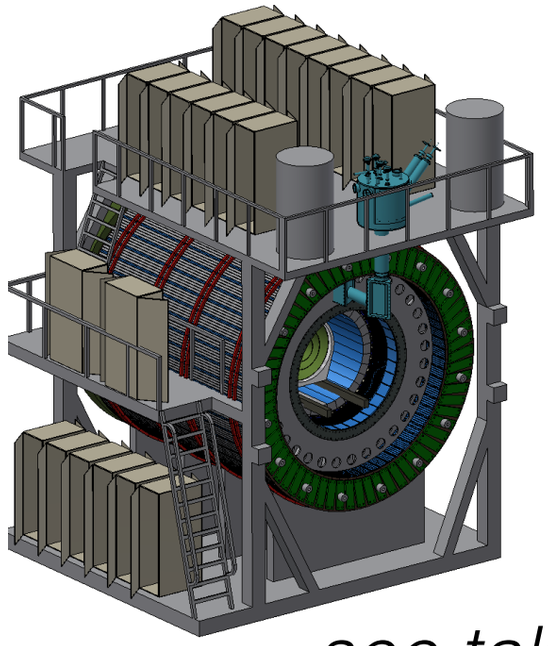


vs. jet p_T

vs. N_{part}

- Preliminary measurement of R_{AA} in relatively novel system
  - ➡ in 0-20% collisions, R_{AA}~0.5 and is p_T-independent
  - ➡ differential suppression with increasing N_{part}
- For more information, see *QM15 talk & proceedings by A. Timilsina*

Summary



- Progress on jet measurements in small and large systems with PHENIX detector

  ➡ good guidance for *future heavy ion jet program at RHIC*

see talk by D. Morrison

- Jet rate in *p*+*p* and minimum bias *d*+Au collisions establish pQCD / nPDF baseline

  ➡ *limits on initial/final state energy* loss over wide p_T

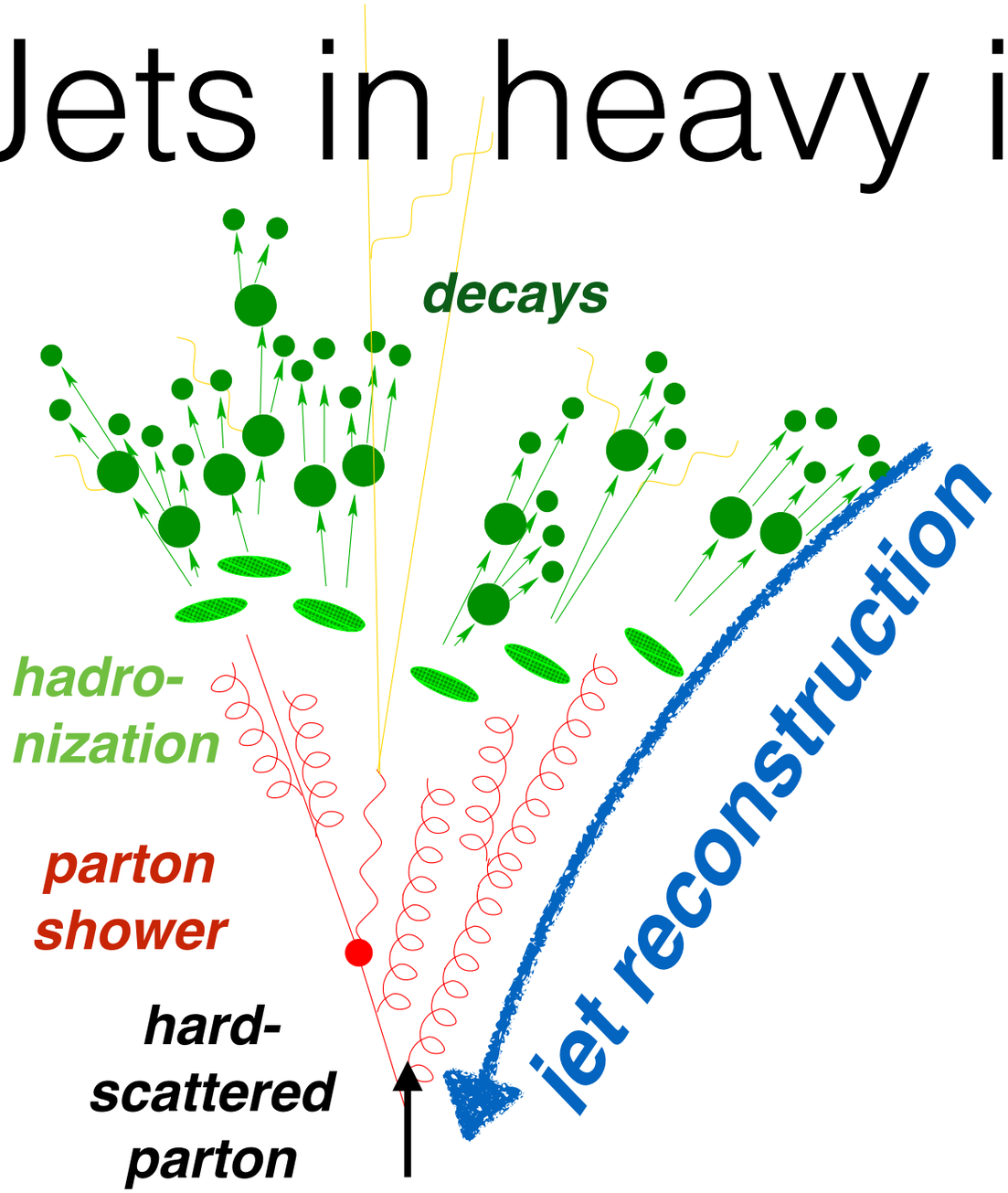
- Surprising, unexpected centrality dependence

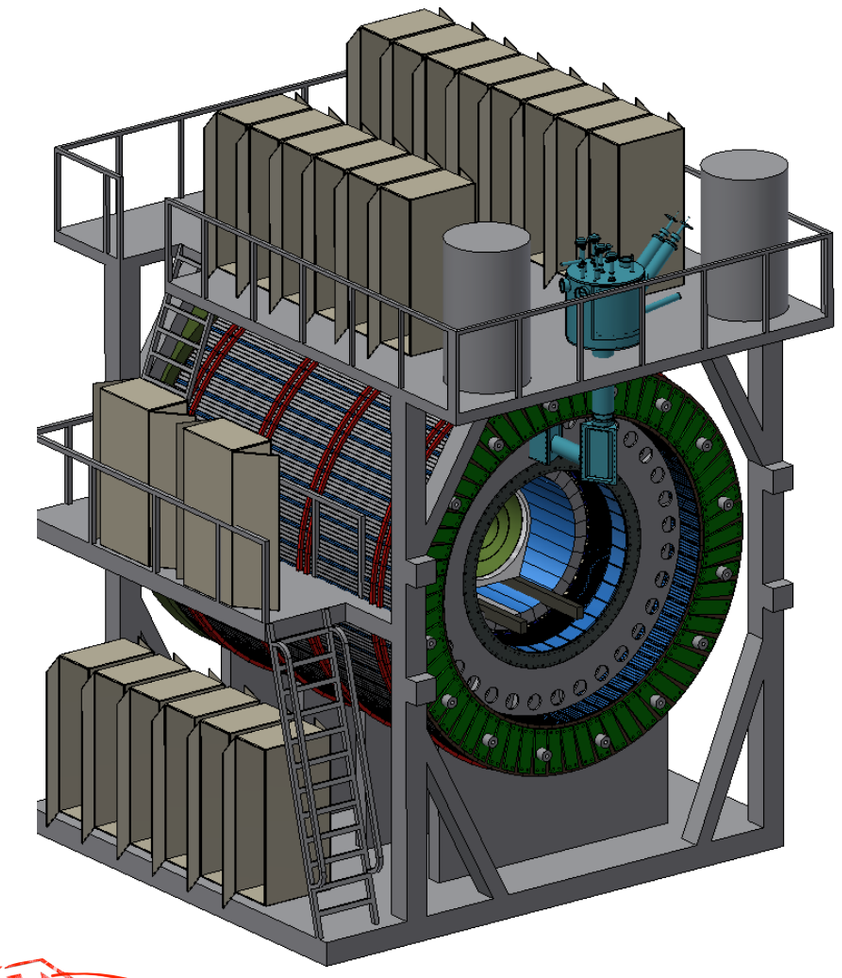
  ➡ one possibility: are we sensitive to the fact that *large-x nucleons are "smaller" than average*?

- Preliminary measurement of jet suppression in Cu+Au

backup

Jets in heavy ion collisions





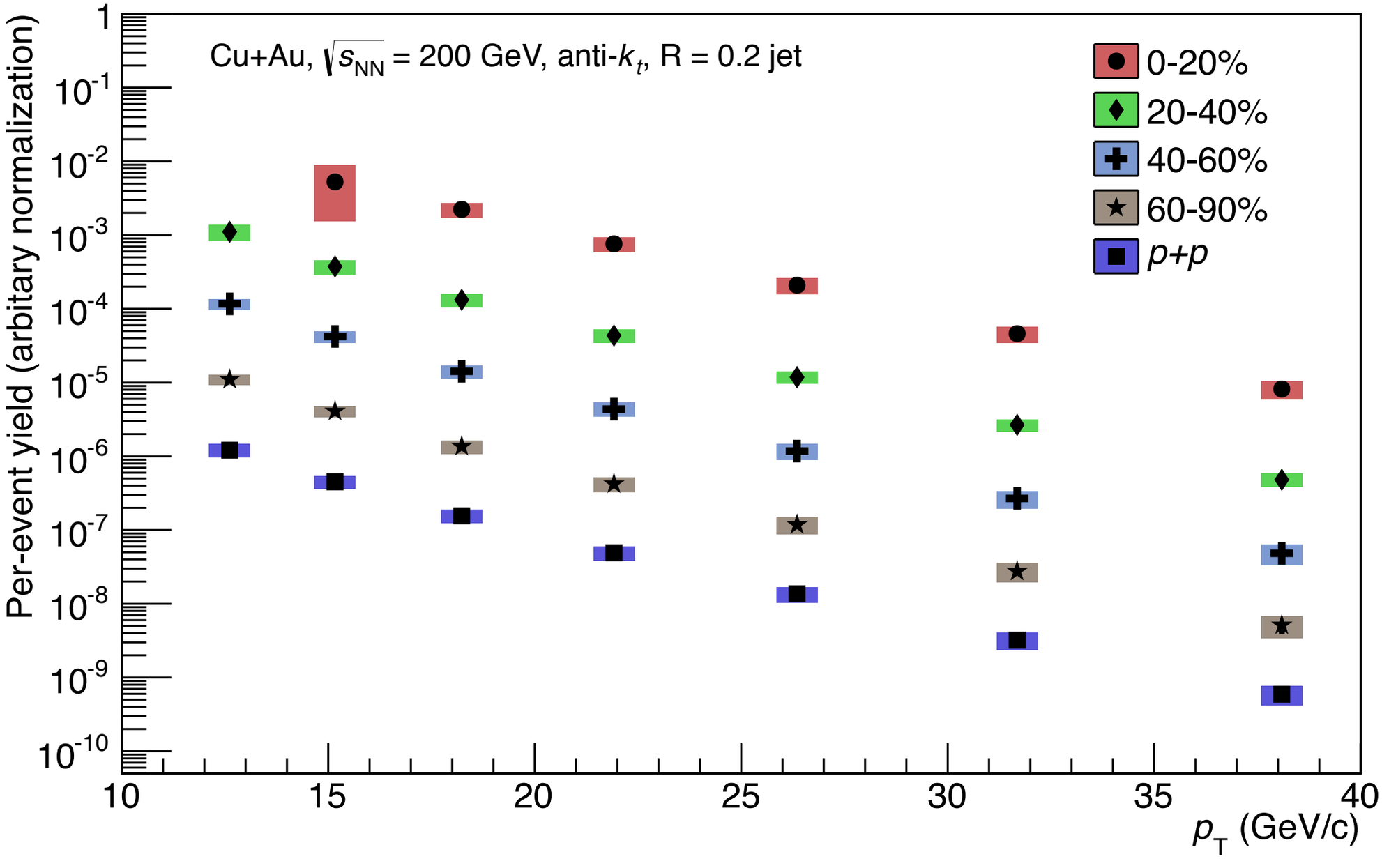
PHENIX

see talk by D. Morrison

- Jets are most abundant final-state QCD object
- Full jet reconstruction difficult but rewarding in HI collisions

  ➡ in this talk, *progress in jets from PHENIX at RHIC*

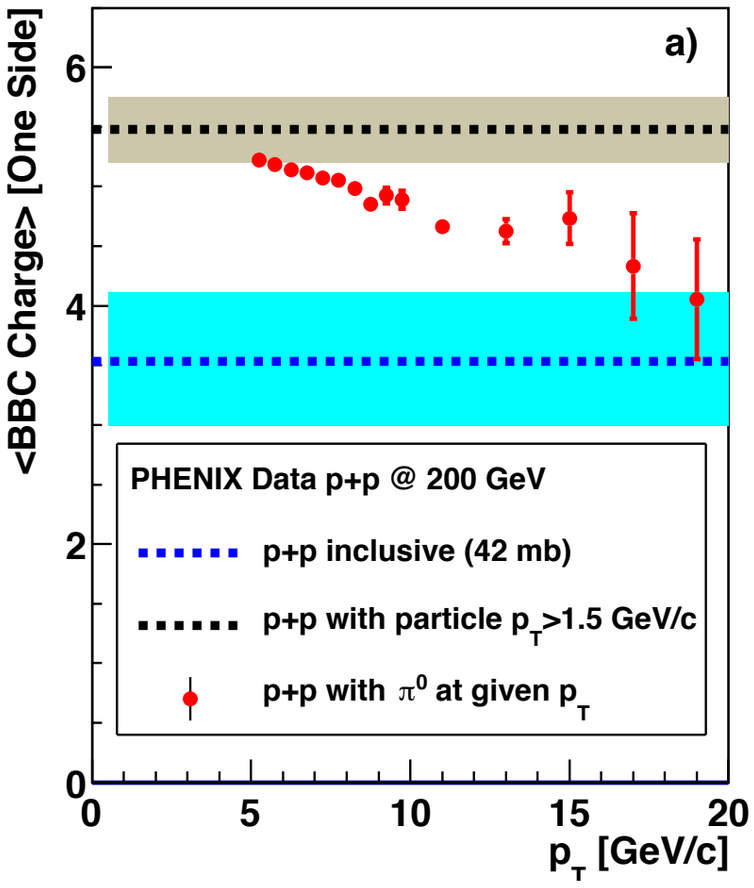
Jet spectra in *p*+*p* and Cu+Au

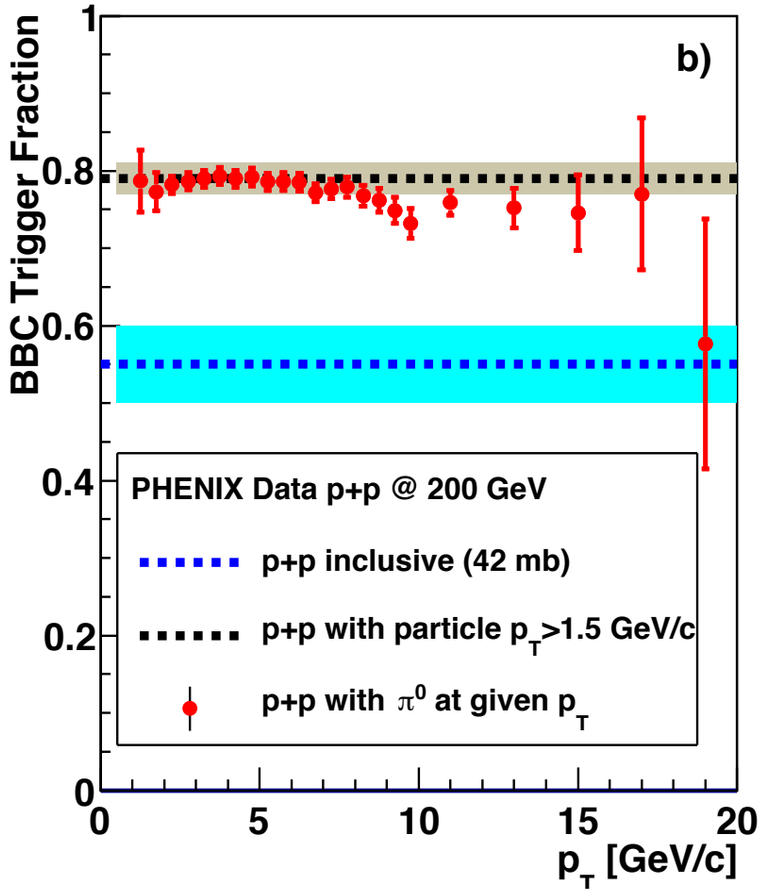


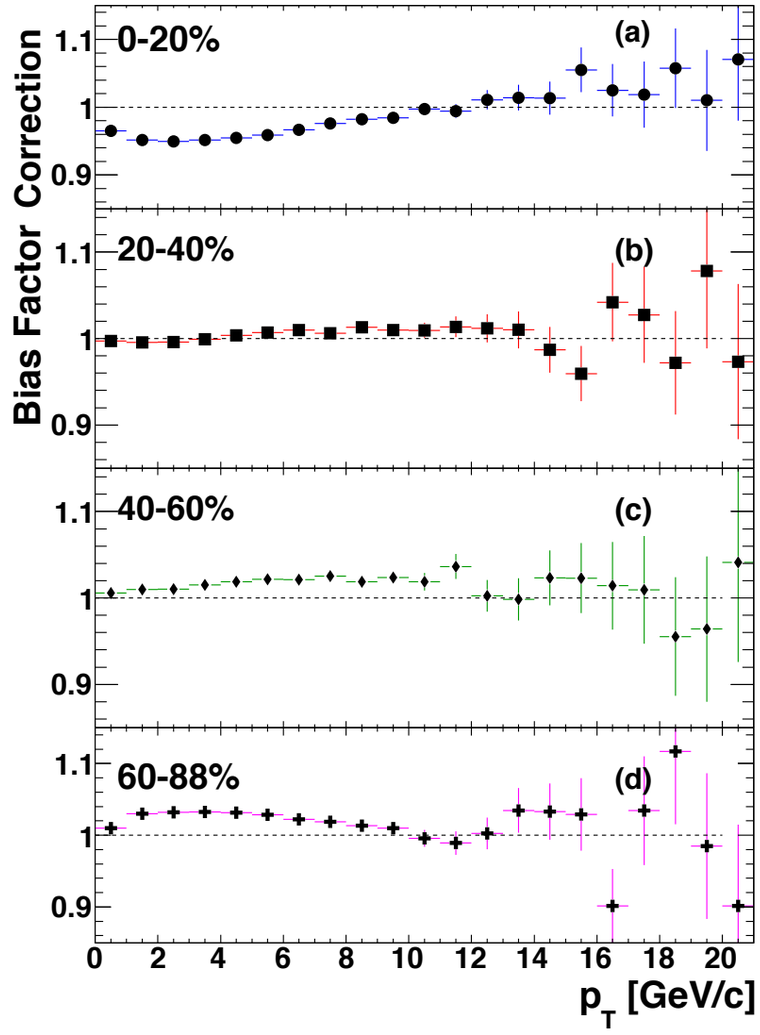
- For preliminary results, arbitrary normalization, but <u>*p*+*p*-to-Cu+Au normalization is fixed</u>
- Expanded systematics for **low-p_T jets in most central events**

Centrality w/ hard processes

PRC 90 (2014) 034902

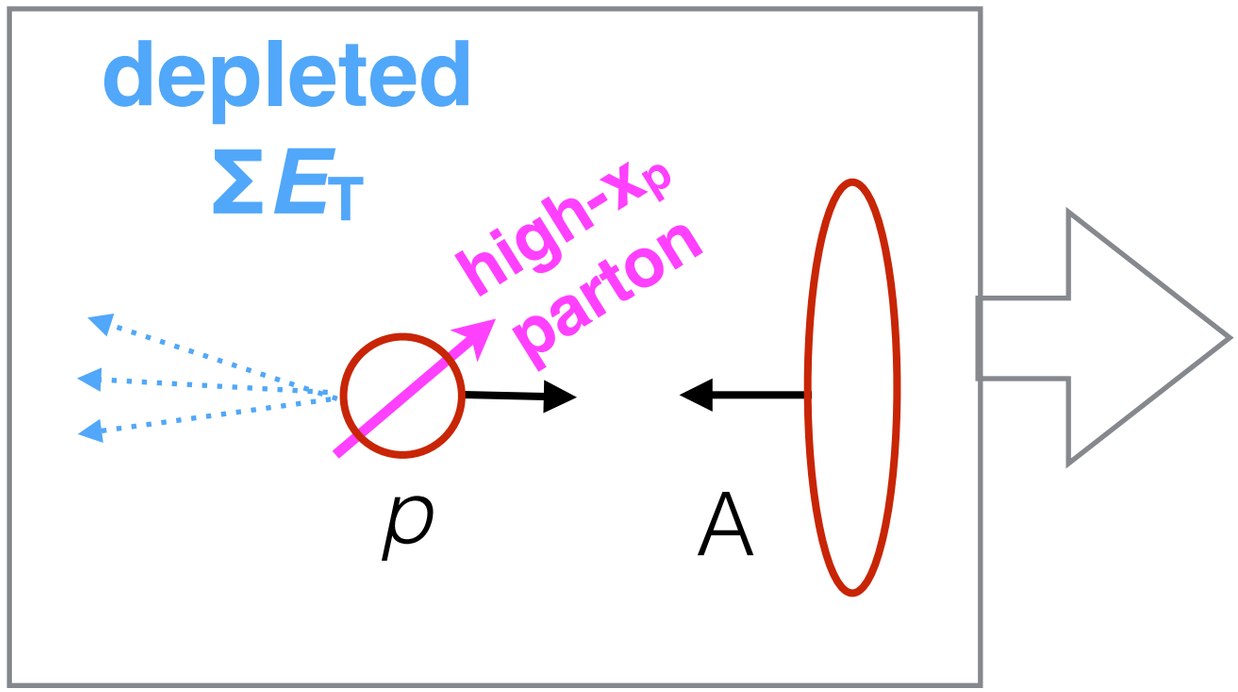




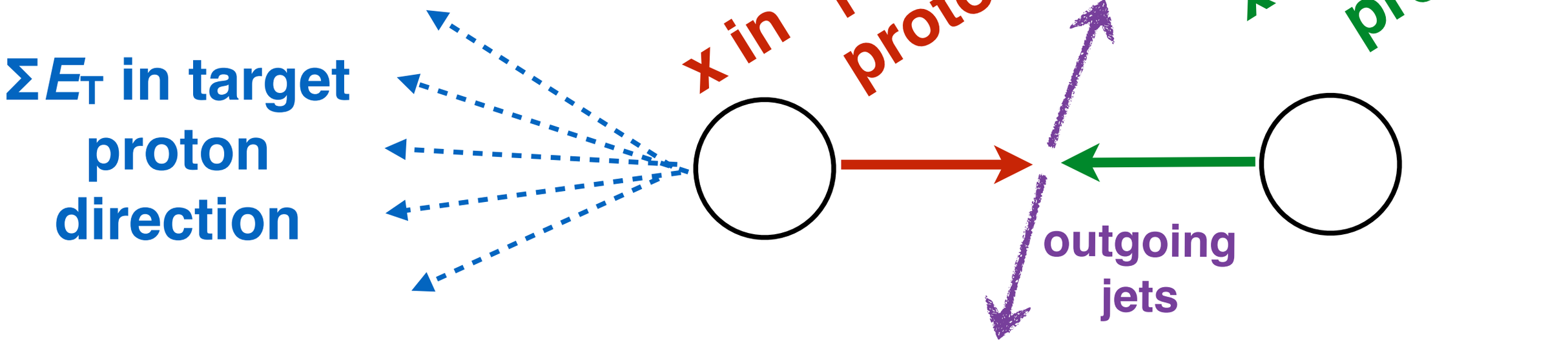


- Could this be a *bias* or *auto-correlation* between the centrality signal and the presence of a hard scattering?
  - ➡ PHENIX published PRC 90 (2014) 034902 to address this point with *p*+*p* data and *d*+Au simulation
- Conclusion: there is a small bias which, when corrected for, *magnifies the results*, even for very high-p_T processes

ATLAS, PLB 756 (2016)

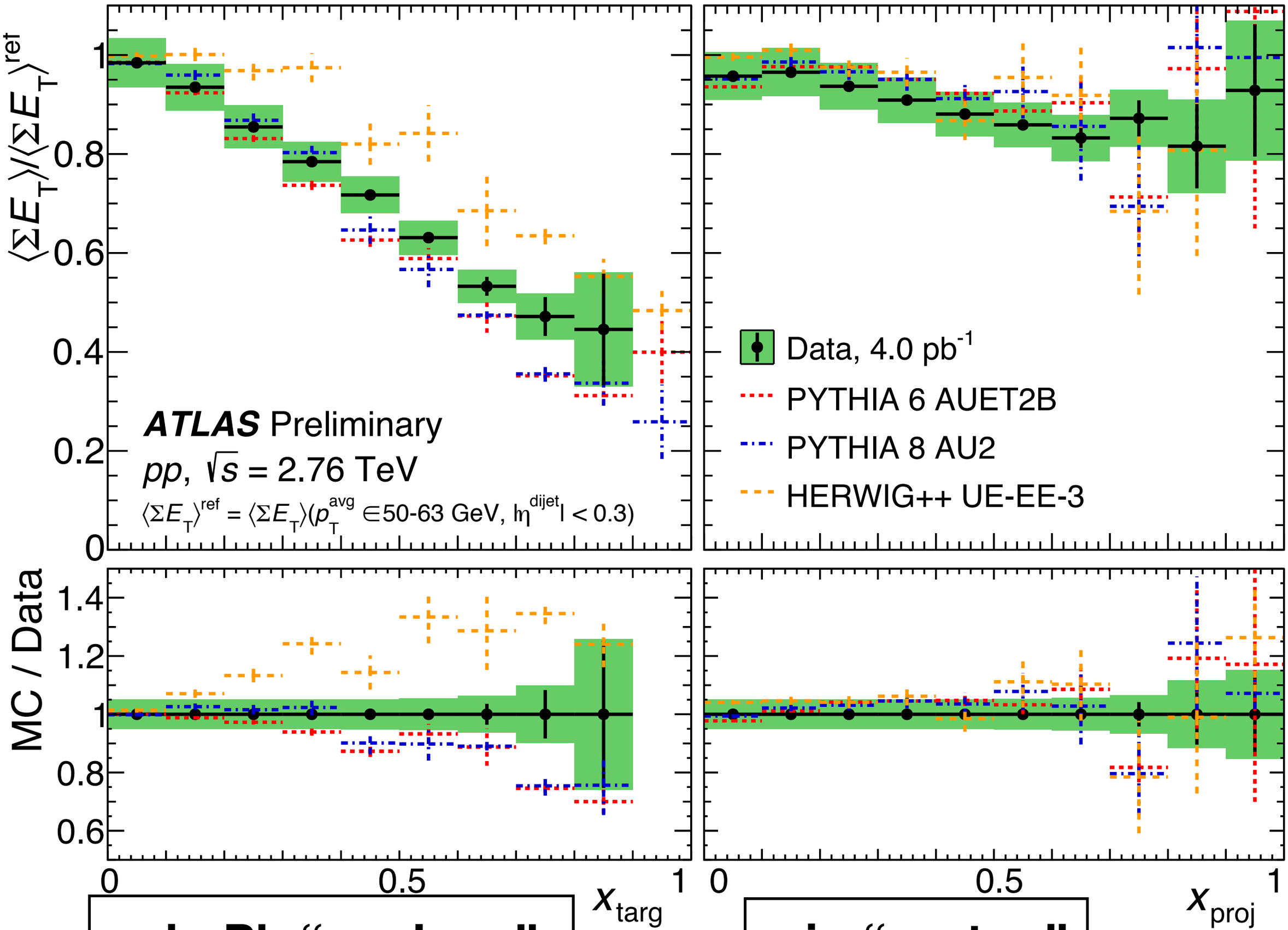


is this just a feature of *pp* collisions?



Measure ΣE_T at large pseudorapidity vs.
x in the **projectile** proton (moving away)
x in the **target** proton (moving towards)

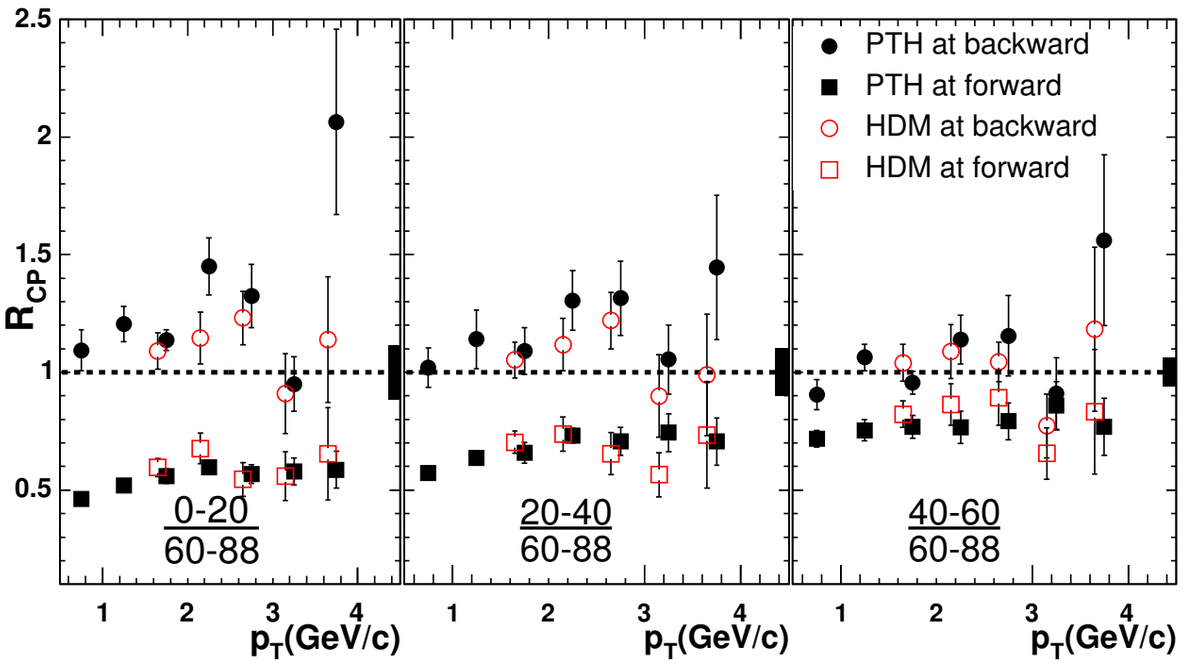
ATLAS, PLB 756 (2016)

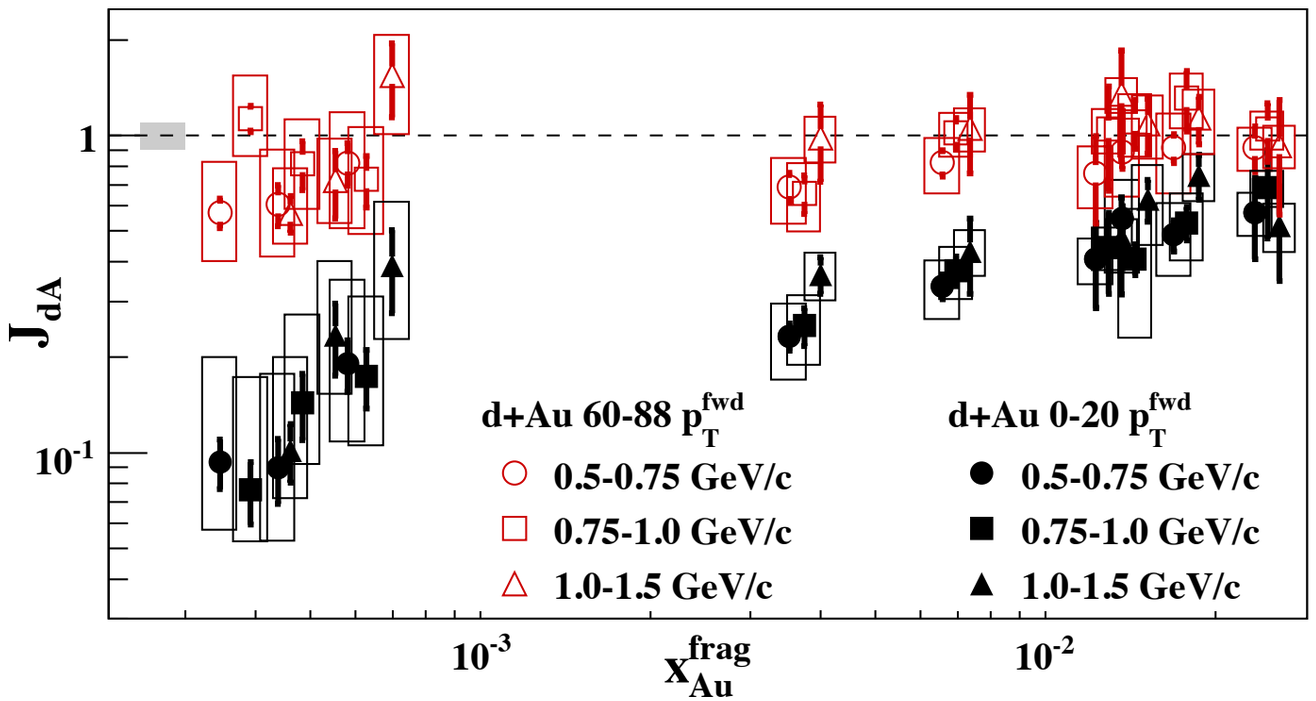


***x* in Pb "nucleon"**

***x* in "proton"**

New angle on previous data?





- Strong *centrality dependence* in forward hadron and di-hadron production in *d*+Au
  - ➡ even though <*b*> does not change so much
  - ➡ attributed by many to low nuclear-*x* effects (CGC?), but kinematic region also associated with large deuteron-*x*
- My two cents: there's an overall suppression, but most of the centrality "dependence" is from large x_d, **not** small x_{Au}

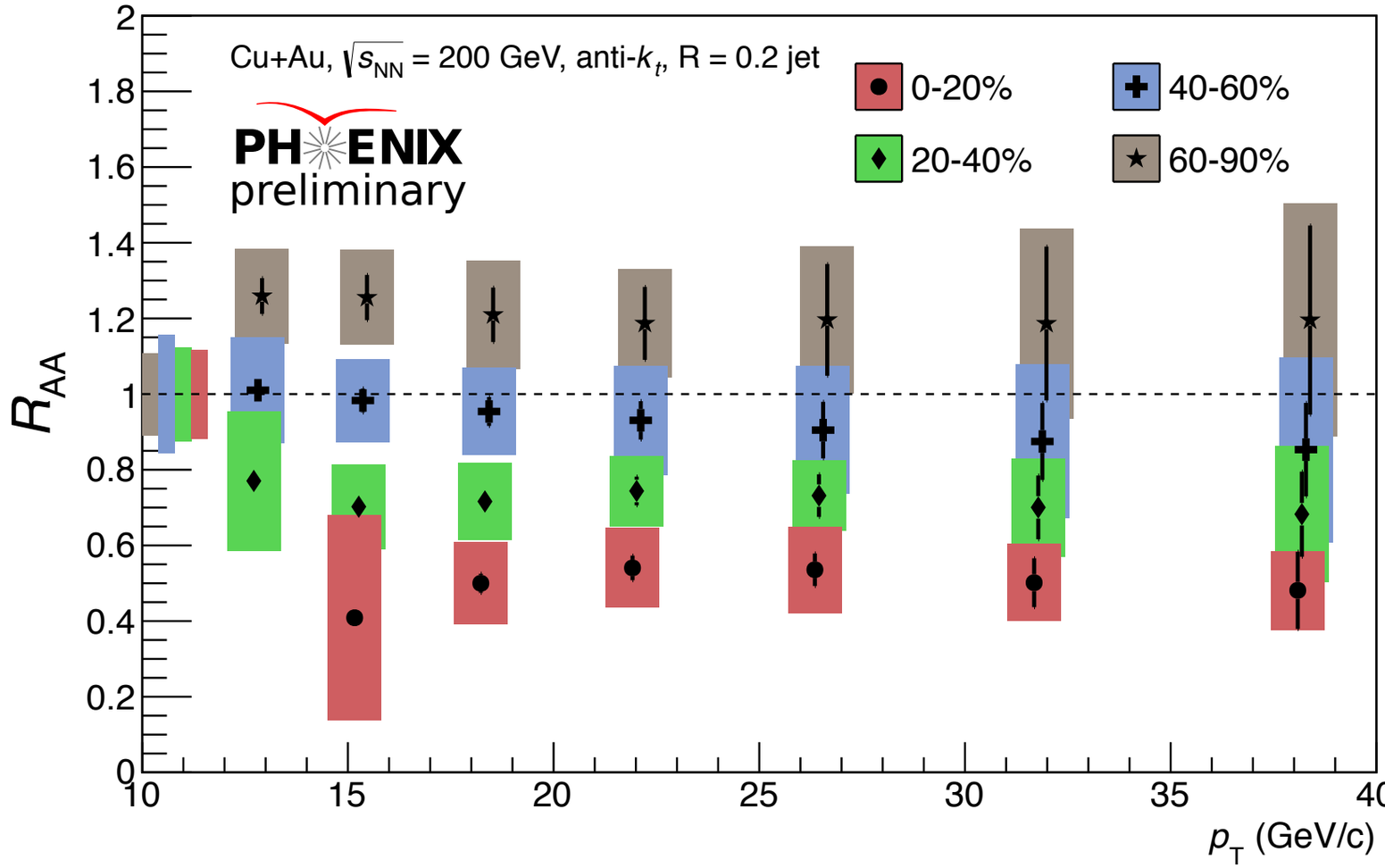
Jet suppression in Cu+Au

Cu+Au yield

$$R_{AA} = \mathbf{dN/dp_T} \;/\; \mathbf{T_{AA}} \times \mathbf{d\sigma/dp_T}$$

nuclear *p+p*

overlap *x-sect.*



- Differential, centrality-dependent suppression of N_{coll}-scaled yield
  - ➡ **peripheral events** just consistent with $R_{AA} = 1$
  - ➡ factor of 2 suppression in **central events**
- Interestingly, flat with p_T